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Optimal planning of distributed generation systems in distribution system: A review

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ABSTRACT

This paper attempts to present the state of art of research work carried out on the optimal planning of distributed generation (DG) systems under different aspects. There are number of important issues to be considered while carrying out studies related to the planning and operational aspects of DG. The planning of the electric system with the presence of DG requires the definition of several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer, when dealing with the increase of DG penetration that is happening nowadays. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem.

This paper aims at providing a review of the relevant aspects related to DG and its impact that DG might have on the operation of distributed networks. This paper covers the review of basics of DG, DG definition, current status of DG technologies, potential advantages and disadvantages, review for optimal placement of DG systems, optimizations techniques/methodologies used in optimal planning of DG in distribution systems. An attempt has been made to judge that which methodologies/ techniques are suitable for optimal placement of DG systems based on the available literature and detail comparison(s) of each one.

Contents

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1. Introduction

Distributed generation, also called on-site generation, dispersed generation, embedded generation (EG), decentralized generation, decentralized energy, situ generation or distributed energy, generates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal, gas powered), nuclear, large solar power plants or hydropower plants. However, modern embedded systems can provide these traits with automated operation and renewables, such as sunlight, wind and geothermal [1–143]. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. In the line of above distributed energy resource (DER) systems are small-scale power generation technologies (typically in the range from 3 kW to 10,000 kW) used to provide an alternative to or an enhancement of the traditional electric power system [2,10].

DG has always been an attractive alternative for rural areas where transmission and distribution (T&D) costs are high, and DG is quickly becoming an attractive option for more densely populated regions due to the uncertainties associated with industry restructuring and difficulties in permitting discourage new T&D investments [3–6]. The detailed comparison between distributed resource power system and conventional central station generation with T&D system, on the basis of various performance characteristics such as efficiency and losses, voltage profile improvement, reliability and power quality, investment, fuel, operation and maintenance (O&M), emissions, etc. is given in [7,8]. The application(s) of small generators scattered throughout the power system will cope up with the growing demand for electricity in certain areas and render certain activities self-sufficient in terms of power production and achieving energy savings DG is best suited for demand side management programs [9].

The technologies adopted in DG comprise small gas turbines, micro-turbines, fuel cells, wind and solar energy, biomass, small hydro-power etc. [10–12]. DG can be used in an isolated way, supplying the consumer's local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system. Fig.1 depicted difference between the central utility of today and distributed utility of tomorrow [44].

It often offers a valuable alternative to traditional sources of electric power for industrial, commercial and residential applications so it appears as an alternative that utility planners should explore in their search for the best solution to electric supply problems. The main reasons for the increasingly widespread use of DG can be summed up as follows [2,4,10,11,13–15,23,25,27,113]:

- DG units are closer to customers so that T&D costs are avoided or reduced.
- T&D costs have risen while DG costs have dropped; as a result the avoided costs produced by DG are increasing.
- The latest technology has made available plants with high efficiency and ranging in capacity from few kW to hundreds of MW of different DGs.
- It is easier to find sites for small generators.
- Natural gas, often used as fuel in DG stations, is distributed almost everywhere and stable prices are to be expected.
- Usually, DG plants require shorter installation times and the investment risk is not so high.
- DG plants yield fairly good efficiencies especially in cogeneration and in combined cycles (larger plants).
- The liberalization of the electricity market contributes to creating opportunities for new utilities in the power generation sector.
- DG offers great values as it provides a flexible way to choose a wide range of combinations of cost and reliability.

Parallel to the introduction of DG; when distribution system planning and DG impact are considered, the greatest attention should be paid in the siting and sizing of DG units because their installation in non-optimal locations can result both in an increasing of power losses and in a reducing of reliability levels [14,16,17]. Then proper tools, able to find the siting and sizing of DG units which reduces at maximum the costs while satisfying technical constraints can aid for the planner who has to face with the worldwide growth of DG penetration [15,18]. From distribution system planning point of view, DG is a feasible alternative for new capacity especially in the competitive electricity market environment and has immense benefits such as:

- Short lead time and low investment risk since it is built in modules.
- Small-capacity modules that can track load variation more closely.
- Small physical size that can be installed at load centers and does not need government approval or search for utility territory and land availability [20,21].
- Existence of a vast range of DG technologies [19].

Distribution systems have traditionally been designed to operate with unidirectional power flow, from the source (transmission system) to the loads. Adding DG to a distribution system imposes a different set of operating conditions on the network, namely reverse power flow, voltage rise, increased fault levels, reduced power losses, harmonic distortion and stability problems [22]. The optimal locations of distributed resources should be identified in a network in order to minimize losses, line loadings, and reactive power requirement. The foreseeable large use of DG in the future requires to distribution system engineers to properly take into account its impact in the system siting and sizing.

2. Distributed generation definition

Different definitions regarding DG are used in the literature and in practice. These variations in the definition can cause confusion. According to Electric Power Research Institute (EPRI) defines DG as generation from 'a few kilowatts up to 50 MW' [10]. In Refs. [10,36–39], a large number of terms and definitions are used in

Nomenclature

T_i	time duration
$I_d(x,T_i)$	phasor feeder current at point x
I_i	current magnitude
B	number of branches
P_{LP} and P_{LQ}	active and reactive component of branch power
I_{ai} and I_{ri}	active and reactive component of branch current
R_i	ith branch resistance and the branch resistance vector
nb	number of branches
P_G	generation power
P_D	demand power
P_L	real power losses
P_{DGi}^{CAP}	the DG capacity limit (MV A)
P_{SS}	the amount of power purchased by the disco
P_{Ue}	unserved power (MV A)
C_{Ue}	cost of unserved power ($/MV A-h)
ρ	electricity market price ($/MWh)
C_{fi}	hourly DG investment cost ($/MV A-h)
C_{ri}	hourly DG operating cost ($/MV A-h)
Z	value of objective function ($)
ncd	number of candidate site for DG placement in the network
nld	number of load level in year
nss	number of HV/MV substation in the system
nyr	planning period (year)
C_{DG}	selected capacity of DG for installation in node i (MV A)
K_{IDG}	investment cost of DG sources ($/MV A)
K_{EDG}	operation cost of DG sources including maintenance cost ($/MWh)
K_{SSl}	energy market price in load level l ($/MWh)
$P_{SSj,i}$	power dispatched from substation j at load level l including network losses (MW)
$C_{i,l}$	generated power by DG source installed in node i at load level l (MW)
PW	present worth factor
IntR	the interest rate
InfR	the inflation rate
N_{Tot}	the number of network nodes
N_{Cp}	the number of substations
$N_{Tot}-N_{cp}$	the number of branches in the network
F_{oj}	the present cost of the jth branch
Benefit^{DG}	the benefits of DG
Cost^{DG}	cost of DG
N_G	the total number of DG installed in the feeder
K_A	the cost for power ($/kW-h)
ΔPloss	the average power loss reduction per year due to the DG placement
$\text{DG}_{gen,i}^{avg}$	the average generation of DG i per year
CIC^{DG}	is the customer interruption cost (CIC) of a distribution feeder with the DG placement
CIC^{o}	the CIC prior to the DG placement
$\text{Cost}_{inv,i}$	investments costs of DG i per year
$\text{Cost}_{main,i}$	maintenance costs of DG i per year
$\text{Cost}_{oper,i}$	operating costs of DG i per year
CPV	cumulative present value
S_{ij}	complex power from bus i to j
S_{ji}	complex power from bus j to i
$S_{Loss\ ij}$	the power loss in line i–j
P_i	the real power generation at the ith generator bus
B_{ij}	$n \times n$ matrix
B_{io}	the constant of loss coefficients
Benefit (B)	losses cost (before the DG installation)- losses cost (after the DG installation)
Total cost (C)	investment cost + installation cost + maintenance cost
$\text{Voltage\%}_{i\ without\ DG}$	voltage percent in ith bus without DG resource
$\text{Voltage\%}_{i\ with\ DG}$	voltage percent in ith bus with DG resource
$P_{j\ with\ DG}$	active power losses in jth branch with DG resource
$P_{j\ without\ DG}$	active Power Losses in jth branch without DG resource
$Q_{j\ with\ DG}$	reactive power losses in jth branch with DG resource
$Q_{j\ without\ DG}$	reactive power losses in jth branch without DG resource
$k1$, $k2$, $k3$	emphasis or penalty factors
n	number of buses
m	number of branches
C and E	net discounted costs (£) and energy (kWh) over the entire planning period respectively
X	the solution vector
C_i	the overall cost (£) incurred in year i
E_i	the expected energy sold (kWh) in year i
R	discount rate
Y	the planning period in years
$X(U)$	a power flow solution a power flow solution of vector U
C_U	cost of network upgrading
C_L	cost of energy losses
C_{ENS}	cost of energy not supplied
C_E	cost of purchased energy
F_1	the cost of energy losses
F_2	the voltage profile
F_3	total harmonic distortion (THD) index
f_{OPF}	the generator capacity cost function
C_g	the benefit the DNO derives from connecting generator g of capacity P_g
$\tilde{f}_M$	the monetary objective function ($)
NN	the total number of network nodes
C_{DGi}	the DG capacity in the ith location (MV A)
IC_{DG}	the DG investment cost ($/MV A)
T	the horizon planning year (year)
P_{DGi}	the power generated from DG at the ith location (MW)
OC_{DG}	DG operation cost ($/MW h)
α_N	the set of doubles whose elements are indices of nodes connected by line segments
$\Delta\tilde{V}_{i,j}$	the voltage drop across the line segment connecting nodes i and j (V)
$R_{i,j}$	the line segment resistance from node i to j (V)
$Z_{i,j}$	the line segment impedance from nodes i to j (V)
C_T	the electricity market price ($/MW h)
d	the discount rate
$\tilde{P}_{Loss0}$	the network power losses before DG placement (MW)
P_{Loss}	the network power losses after DG placement (MW)
K_e	is the constants for energy
P_{loss}^{i}	is the power loss for load level i with a time duration T
nt	the number of load levels
C	total Cost of DG
C_P+C_Q	generation cost of DG
C_I	installation cost of DG
P_i	the nodal injected power at bus i
P_k	load power of bus k
L	total number of load buses
α	penalty weight of equality constraint
C^*	constant as capacity in MW of DG
P_{kj}	load power of bus k at the jth feeder
P_{hj}	power losses of harmonic at the jth feeder

B_j	total number of buses at the jth feeder
L_j	total number of load buses at the jth feeder
C_j	total injected power of dispersed generations at the jth feeder
v	value of objective function ($/year)
ic	investment cost of the system ($/year)
oc	operation cost of the system ($/year)
rc	reliability cost of the system ($/year)
C_{RF}	capital recovery factor
EC_{i-t}^{SS}	electricity market price at the ith substation during load level t ($/MW h)
IC^{DG}	investment cost of DG sources ($/MV A)
IC_j^{FD}	investment cost of the jth feeder section ($)
IC_i^{SS}	fixed cost of the ith substation ($)
OC_k^{DG}	operation cost of the kth DG source ($/MV A h
P_{d-t}^{LD}	real power demand of the dth load point at load level t (MW)
P_{k-t}^{DG}	generated power by the kth DG at load level t (MW)
P_{i-t}^{SS}	dispatched real power from the ith substation at load level t (MW)
S_{k-cap}^{DG}	total capacity of the kth DG source (MV A)
S_{k-t}^{DG}	generated power of the kth DG source (MV A)
S_{RS}^{DG}	reserve DG capacity (MV A)
T_t	time duration of load level t (h)
$\lambda_{d,e}$	average failure rate affected load point d in case of each failure event e
$f_d(r_{d,e})$	the per unit cost of outage, based on the outage time r_d, e at the load point d
r_{de}	average restoration time affected load point d in case of each failure event e
$G(x)$	total generator cost (active power dispatch or total losses in the system (reactive power dispatch)
$F(x)$	load flow equation
$H(x)$	transmission line limits with lower and upper limit $\underline{H}$ and $\overline{H}$
P_{Gi}	denotes real power generated at bus i
P_{Di}	denotes real power demand at bus i
P_{DGi}	denotes the power supplied by the DG at bus i
B_i	denotes purchaser benefit functions at bus i
C_i	denotes the producer offer (bid) price at bus i
$C(P_{DGi})$	denote the cost characteristic of DG at bus i
ψ_i	the capacity adjustment factor
MW_i^o	initial machine active power capacity
$-C_i$	negative capacity cost
P_{Load}	active power of the load
Q_{Load}	reactive power of the load
X_{Line}	aggregate reactance of the line connecting the load to the feeding substation
nbr	total number of branches in the system
$\lvert I_i \rvert^2$	magnitude of current flow in branch I
r_i and x_i	resistance and reactance of branch I, respectively
P_{EGi}	the EG capacity at the ith bus.
J	objective function in MW
P_{Tx}	amount of generation demanded from or exported to the transmission system (MW)
P_{DGi} and P_{LDi}	are the DG capacity and the load at the ith bus respectively
η_{ij} and ρ_{ij}	interdependence of losses due to generation and load at the ith bus and generation and load at the jth bus respectively
$C(P_{DG})$	total cost of DG
E	total active loss
W	weighting factor
$P_{elect}^{no_{DG}}$	the price of electricity bill without incorporating DG
P_{elect}^{DG}	the price of electricity bill with incorporating DG
BPV	benefit present worth
B_1	active power reduction benefit
B_2	reliability enhancement benefit
C_1	investment cost
C_2	maintenance cost
C_3	operation cost of DG
f_1	the profit function
f_2	the technical function
f_3	the environmental function

connection with the DG. Therefore, in [1,3,8,9,10,14,15,20,23–29, 30–33] suggested an approach towards a general definition of distributed generation. The general definition for distributed generation suggested here is:

> "Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter".

The above definition of DG does not state the meaning of generation sources, as the maximum rating vary according to the local distribution network conditions e.g. voltage stability, voltage level, feeder current carrying capacity. Therefore, the following categories are suggested of different ratings of DG in Table 1 [34].

In addition to this, the definition does neither explain the penetration, the ownership, power delivery nor the network operation treatment; as these factors cannot be assumed in general.

As the DG technologies, used very widely, the aforementioned definition does not explain them. However, categorizations of different technologies suggested by Ackermann et al. [10] are:

Renewable—distributed generation.
Modular—distributed generation.
Combined heat and power (CHP)—distributed generation.

2.1. Distributed generation technologies

Distributed generation takes place on two-levels [23]: the local level and the end-point level. Local level power generation plants often include renewable energy technologies that are site specific, such as wind turbines, geothermal energy production, solar systems (photovoltaic and combustion), and some hydro-thermal plants. These plants tend to be smaller and less centralized than the traditional model plants. They also are frequently more energy and cost efficient and more reliable. Since these local level DG producers often take into account the local context, the usually produce less environmentally damaging or disrupting energy than the larger central model plants [1,23,25,27].

At the end-point level the individual energy consumer can apply many of these same technologies with similar effects. One DG technology frequently employed by end-point users is the modular internal combustion engine. At this level DG technologies can operate as isolated "islands" of electric energy production or they can serve as small contributors to the power grid [25]. Most studies confirm, however, that the penetration of distributed generation up to a level of 10–15% of maximum load can be easily be absorbed by the electricity network without major structural changes. The penetration level in many networks is still below this limit, but this will change. Some significant types of DG technologies are listed in

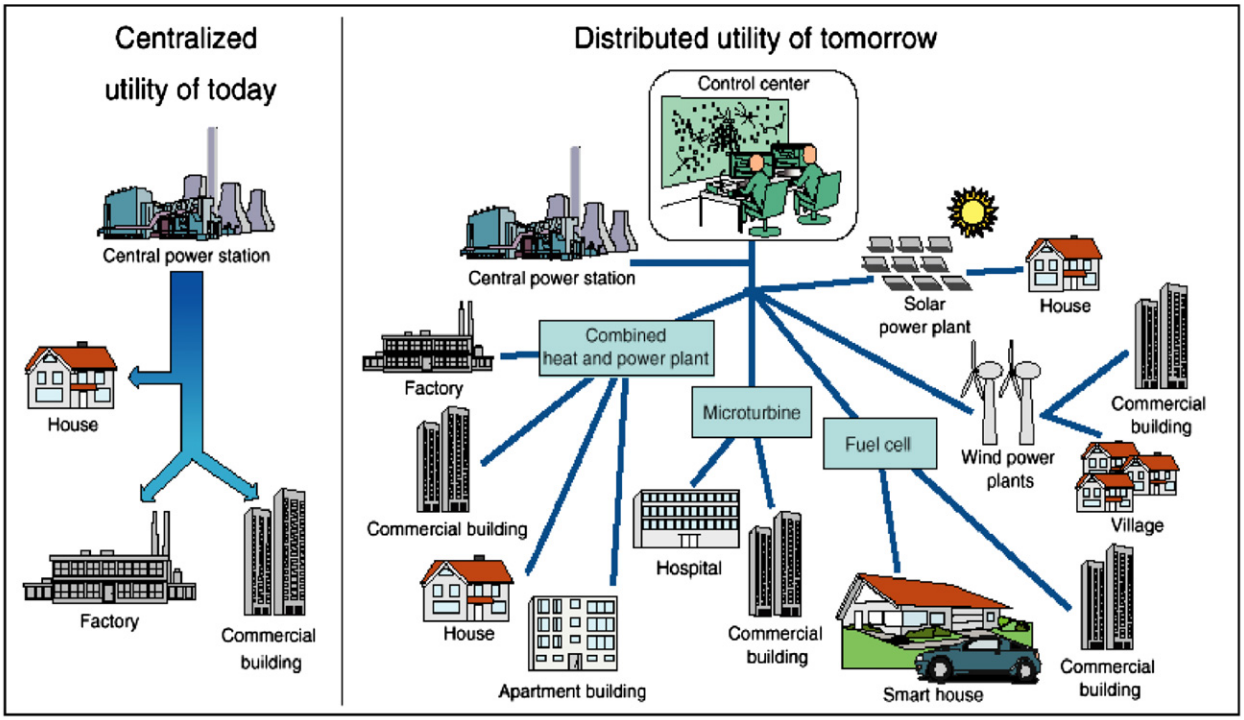

Fig. 1. Central utility of today and distributed utility of tomorrow.

Table 1
Different ratings of distributed generation.

Categories	Ratings
Micro-distributed generation	~1 W < 5 kW
Small distributed generation	5 kW < 5 MW
Medium distributed generation	5 MW < 50 MW
Large distributed generation	50 MW < 300 MW

Table 2; for better ease of construe they categorized in two major headings the non-renewable energy and renewable energy based technologies, along with details reviewed in the literature [23,25,27,35,40]. These are compared based on several parameters such as fuel used, size/module, electrical efficiency, overall efficiency, installed cost, total maintenance cost, peak shaving, reliability, power quality and green power.

2.2. DG applications

The application of various DG technologies depends on the user's individual requirements. The most common technological application(s) of systems is listed below [3,10,23,25,27,29,41–45]:

a. *Base load*: the system operates in parallel with the distribution network. It can take or sell part of the energy and uses the network as support and for the maintenance. The system is running constantly and reduces the consumption of electricity network.
b. *Provide peak load*: it is used to supply electricity during peak periods, thereby reducing peak demand of consumers since the cost of energy in this period is usually the highest.
c. *Support to the distribution network*: sometimes, sporadically or periodically, the electricity company or large customers require it to strengthen its power grid by installing small plants, including the power substation, to avoid and resolve congestions due to high demands at different times of the year or network failures.
d. *Supply quality*: if the quality of the supply is below the needs of the customer, this application provides the required quality eliminating fluctuations.
e. *Energy storage*: this alternative can be considered as a viable alternative when the cost of using technology is variable or when interruptions are frequent or when using renewable energy sources. Backup stand-by supply which ensures the uninterrupted electricity supply. Works only when a power outage.

2.3. DG benefits

Distributed power generation offers a number of opportunities. It can facilitate cleaner power production, since many DG units utilize renewable energy sources are based on CHP. Renewable energy sources, such as wind and sunlight, are distributed by nature and the same is true of CHP installations, which, due to their high overall efficiency, can also contribute to lower greenhouse gas emissions. Most of the benefits of employing DG in existing distribution networks have both economic and technical implications and they are interrelated. As such, it is proposed to classify the benefits into three groups; Technical, Economical and environmental benefits [17,19,32,46–52]. Table 3 shows the benefits matrix of various categories of DG services.

2.3.1. Technical benefits

Technical benefits cover a wide variety of issues such as peak load shaving, good voltage profile, reduced system losses, improved continuity and reliability and removal of some power quality problems. Reducing the total system losses could be of interest to some utilities in the developing countries as some of

Table 2
DG technologies.

S. no.	Type of technologies	Fuel used	Size/module (kW)	Electrical efficiency (LHV[a]) (%) [27]	Overall efficiency (%)	Installed cost ($/kW)	Total maintenance cost ($/kW)	Peak shaving	Reliability	Power quality	Green power
A	**Non-renewable energy based technologies**										
1	Reciprocating engines	Diesel, gas or natural gas	3–6000+	30–43	~80–85	600–1200	0.005–0.015	Yes	Yes	Yes	No
2	Combustion gas turbine	Gas or diesel	0.5–30,000+	21–40	~80–90	400–900	0.004–0.010	Yes	Yes	Yes	No
3	Micro-turbine	Bio-gas, propane or natural gas	30–1000	14–30	~80–85	1200–1700	0.0018–0.015	Yes	Yes	Yes	No
4	Hybrid fuel cell	Ethenol,H2,N2 natural gas, phosphoric acid, or propane	400–20,000	35–55	~80–85	4000–5000	0.0019–0.0153	Yes	Yes	Yes	No
5	Small fuel cell	Ethenol,H2,N2 natural gas, or propane	1–300	30–50	~80–90	4000–5000	0.0019–0.0153	Yes	Yes	Yes	No
6	Micro CHP	Heat space or water	1–10	30+	~75–89	500–845	–	Yes	Yes	Yes	No
7	Automotive fuel cells	Ethenol,H2,N2 natural gas, PEM, phosphoric acid or propane	30–60	30–55 (hydrogen to electricity)	~80–90	4000–5000	0.0019–0.0153	Yes	Yes	Yes	No
B	**Renewable energy based technologies**										
1	Wind	Wind	0.2–3000	NA	~50–80	–	–	No	No	No	Yes
2	Photovoltaic systems	Sun	0.02–1000+	NA	~40–45	4500–6000	–	No	No	No	Yes
3	Biomass gasification	Biomass	100–20,000	15–25	~60–75	1500–3000	–	No	No	No	Yes
4	Small hydro-power (SHP)	Water	5–100,000	NA	~90–98	10,000–13,000	–	No	Yes	Yes	Yes
5	Geothermal	Hot water	5000–100,000	10–32	~35–50	–	–	No	No	No	Yes
6	Ocean energy	Ocean wave	100–1000	–	–	–	–	No	No	No	Yes
7	Solar, thermal	Sun and water	1000–80,000	30–40	~50–75		–	No	No	No	Yes
8	Battery storage	–	500–5000	NA	~70–75	100–200	–	Yes	yes	yes	Yes

NA, not Applicable.
[a] LHV, lower heat value.

Table 3
Matrix of benefits of distributed generation.

DG services	Benefits categories						
	Energy cost savings	Savings in T&D losses and congestion costs	Deferred generation capacity	Deferred T&D capacity	System reliability benefits	Power quality benefits	Land use effects
Reduction in peak power requirements	✓	✓	✓	✓	✓	✓	✓
Provision of ancillary services – Operating reserves – Regulation – Blackstart – Reactive power	✓	✓	✓	✓	✓	✓	✓
Emergency power supply	✓	✓			✓	✓	

them are losing 15–20% of their total generation as losses while this figure for a well-developed power system is well under 10%. However, the placement and size of the DG are two crucial factors in loss reduction as will be shown in the literature. The major technical benefits are [17,19,45,47,49,53–57]:

a. Reduced line losses.
b. Voltage profile improvement.
c. Increased overall energy efficiency.
d. Enhanced system reliability and security.
e. Improved power quality.
f. Relieved T&D congestion.

2.3.2. *Economical Benefits*

Economical advantages cover saving world fuel, saving transmission and distribution cost and reducing whole sale electricity price. The major technical benefits are [48,49,52, 54–56,58]:

a. Deferred investments for upgrades of facilities.
b. Reduced O&M costs of some DG technologies.
c. Enhanced productivity.
d. Reduced health care costs due to improved environment.
e. Reduced fuel costs due to increased overall efficiency.
f. Reduced reserve requirements and the associated costs.
g. Lower operating costs due to peak shaving.
h. Increased security for critical loads.

2.3.3. *Environmental benefits*

Environmentalists and academics suggest that DG technologies can provide ancillary benefits to society as compared to large centralized power plants. On the other hand, recent studies have confirmed that widespread use of DG technologies substantially reduces emissions: a British analysis estimated that domestic combined heat and power technologies reduced carbon dioxide emissions by 41% in 1999; a similar report on the Danish power system observed that widespread use of DG technologies have cut emissions by 30% from 1998 to 2001. Finally, DG can help the nation increase its diversity of energy sources [25].

Some of the DG technologies, such as renewable energy technologies including wind turbines, solar photovoltaic panels, and hydroelectric turbines, consume no fossil fuels, while others, such as fuel cells, microturbines, and some internal combustion units burn natural gas, much of which is produced in the United States. The increasing diversity helps insulate the economy from price shocks, interruptions, and fuel shortages. Customers who are environmentally inclined may purchase these DG applications for these reasons, even if they pay a slight premium for green power compared with grid based purchases. On the other hand environmental advantages include low noise and low emission and more green power.

2.4. *DG issues and limitations*

However, when the penetration of the DG becomes significant, the system dynamics can be affected. In this sense, the DG interconnection analysis is complex, especially taking into account the wide variety of technologies and the typical configuration of the distribution networks, which have been designed to operate with power flows only in one direction. Researchers and systems operators will need to these challenges; when incorporating DG on a large scale [43,59–66]. These limitations may be enumerated as below:

a. *Reverse power flow*: as a result of connecting DG in the system causing malfunctions of protection circuits as they are configured at present.
b. *Reactive power*: many DG technologies use asynchronous generators that do not supply reactive power to the grid.
c. *System frequency*: deviations from the system nominal frequency are caused by unbalances between supply and demand. The increase in the amount of distributed generation affects the system frequency and these generators have the potential to become "free riders" making the process of control more complicated.
d. *Voltage levels*: the installed distributed generation changes the voltages profile of the distribution network because of the change in the magnitudes of power flow. Usually the voltages profile will tend to rise, which is not a problem in congested networks with low voltage problems, as would be in the contrary.
e. *Protection schemes*: as already mentioned, the majority of the distribution networks are configured in radial form, and most of them at split rings. This generates unidirectional flow patterns, and so the protections system is designed accordingly. The installation of distributed generation changes the flow into bidirectional, and so necessarily implying new safety equipment and resizing of the network (grounding, short-circuit, breaking capacity, Supervisory Control and Data Acquisition (SCADA) systems etc.)
f. Islanding protection is an important security, this is, a condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system. A DG may be feeding a short circuit, thereby generating the possibility of

fire or energizing a certain segment of the network, which may cause a risk of death to workers who come into contact with it when not timely advised of the possibility of it being energized. One way of solution is to place protective equipment such as relays (electronic or mechanical) and transfer switches

g. Harmonics injection into the system by asynchronous DG sources which use inverters for interconnection.
h. Stability issues.
i. Increased fault currents depending on the location of DG units.
j. High financial cost/kW generation if the renewable energy is used because these technologies are not much matured.
k. Power quality is a problem with the application of power electronics to control the SPV wind energy technologies [67–69].

In the different problems have been identified and discussed very clearly; the over-voltage problem at different nodes due to incorporation of DG in the distribution network requires special attention. This is a technical problem which needs to be assessed for proper operation of the distribution network.

3. Impact of distributed generation

As mentioned earlier distribution systems are designed on the assumption that electric power flows from the power system to the load. Therefore, if output fluctuations or a reverse flow from generators occurs on the grid because of DG, there is likely to be some influence on the overall distribution system in terms of power losses, voltage profile, reliability, power quality or protection and safety. The potential impacts of DG are described below [70].

3.1. Power losses

DG causes a significant impact in electric losses due to its proximity to the load centers. DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is similar to capacitor allocation to minimize losses. The main difference is that the DG units cause impact on both the active and reactive power, while the capacitor banks only have impact in the reactive power flow. In feeders with high losses, a small amount of DG strategically allocated (10–20% of the feeder load) could cause a significant reduction of losses [28,71–76].

- With the connection of DG in a system power losses are reduced.
- For a particular DG capacity there is a location in the system such that if we connect DG at that location power losses are minimum in comparison, when same DG is connected at any other point.
- That particular location where power losses are minimum, known as optimum location.

3.2. Voltage profile

The distribution systems are usually regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flows circulating from the substation to the loads. DG introduces meshed power flows that may interfere with the traditionally used regulation practices [28,58,86]. Since the control of voltage regulation is usually based on radial power flows, the inappropriate DG allocation can cause low or over-voltages in the network. On the other hand, the installation of DG can have positive impacts in the distribution system by enabling reactive compensation for voltage control, reducing the losses, contributing for frequency regulation and acting as spinning reserve in main system fault cases [77–78]. Under voltage and over voltage conditions can arise given the incompatibility of DG with the voltage regulation in radial power flows [78–80,83].

3.3. Power quality

Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, with current and voltage in balance [87,91]. To protect the system from degradation in power quality, it is important for network operators to guarantee a specified minimum short-circuit capacity [89].

The relation between distributed generation and power quality is an ambiguous one. On the one hand, many authors stress the healing effects of distributed generation for power quality problems. For example, in areas where voltage support is difficult, distributed generation can contribute because connecting distributed generation generally leads to a rise in voltage in the network [81,82,84–86,88,90] also mention the potential positive effects of distributed generation for voltage support and power factor corrections.

3.3.1. Excess voltage

If there are many DG connections concentrated on a specific line, the gap in the power flow among feeder lines widens because of the back-flow from the DG. This difference might cause the voltage profile of feeder lines to deviate from the proper range [81–85]. The voltage of substation distribution lines is controlled by a programmed timer or line drop compensator (LDC). Generally, a single distribution transformer has several feeder lines, and the voltage for these lines is adjusted in a block.

3.3.2. Voltage fluctuation

The voltage of the local line system is likely to fluctuate if the output of DG changes over a short time, and this fluctuation would cause over or under voltage at the customer's receiving point [91–93]. There is particular concern when generating systems that depend on natural conditions, such as wind power or solar photovoltaic generators, are interconnected to the local system.

3.4. Reliability

The goal of a power system is to supply electricity to its customers in an economical and reliable manner. It is important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers [28,58]. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities has shown that the largest individual contribution for unavailability of supply comes from distribution system failure. One of the main purposes of integrating DG to distribution system is to increase the reliability of power supply [58]. DG can be used as a back-up system or as a main supply. DG can also be operated during peak load periods in order to avoid additional charges.

A basic problem in distribution reliability assessment is measuring the efficacy of past service. A common solution consists of condensing the effects of service interruptions into indices of system performance. Reliability indices are used by system planners and operators as a tool to improve the level of service to customers [94,95]. Planners use them to determine the requirements for generation, transmission, and distribution capacity additions. Operators use them to ensure that the system is robust enough to withstand possible failures without catastrophic consequences. Reliability indices are considered to be reasonable and logic way to judge the performance of an electrical power system. Reliability indices used for the purpose of analysis in this paper are discussed in the next section [75,95–97].

4. Various DGs planning methodologies and their comparison

Aforementioned benefits cannot be maximized except when optimal sizes of DG units are determined and are consequently placed in the best location in distribution systems. To find out the optimal size and location of DG units in power systems has been a major challenge to distribution system planners as well as researchers in the field. In tackling this problem many critical review of different methodologies employed; hence in solving this optimization problem. For ease of reference and to facilitate understating, these literatures categorized and discuss the various existing approaches into five different major headings. They are

i. The analytical approaches.
ii. The meta-heuristics.
iii. The artificial intelligence approaches.
iv. The genetic algorithm (GA) hybrid approaches.
v. Other approaches.

The benefits as well as drawbacks of each approach are thoroughly examined based on the major DGs placement constraint i.e. power losses minimization, improvement of voltage profile, improvement of reliability and power quality.

4.1. The analytical approaches

The analytical approaches typically produce an algebraic expression that can be analyzed for optimization and robustification. This approach is only as accurate as the model developed and it can be very difficult if not impossible for complex systems. The analytical approach might also be used in conjunction with some kind of surrogate model that is based on the results of experiments or numerical simulations of the system. The analytical approaches are surveyed in these studies [21,98,99,101,102,103,104,105,140]. The optimal sites for placement of DGs units are determined exclusively for the various distributed load profiles. Meanwhile, Gozel et al. [21] considered the effects of static load models in determining the optimal size and sites of DG units in distribution systems. Wang and Nehrir [102] were primarily concerned with finding the optimal locations of DG with unity power factor but failed to optimize size. Willis [101] suggested to install DG of aggregate size of approximately 2/3 capacity of the incoming generation at approximately 2/3 of length of the feeder. The additional limitation of this method apart from those; that it cannot support other types of load distribution [102].

The Analytical method used for radial distribution systems by Gozel and Hacaoglu [98] is faster and more accurate than the earlier analytical methods, since the former did not make use of impedance or Jacobian matrices. Acharya et al. [99] the sizing and placement of DG is based on single instantaneous peak demand; where the losses are maximum even though the cost of DG and other associated benefits were not considered in the research. Analytical formulation is proposed that considers the uncertainties involved with wind speed and load demand. The methodology also permits the analysis of distributed wind generators insertion considering different technical and economical parameters [100]. Some of these assumptions are uniformly, increasingly and centrally distributed load profiles which may causes erroneous solutions for real life systems[21]. Duong et al. [140] proposed analytical expressions are based on an improvement to the method that was limited to DG type and minimizing losses in primary distribution systems. The basic objective(s) and objective function(s), the benefits as well as the drawbacks of these approaches are shown in Table 4.

4.2. The meta-heuristic approaches

A meta-heuristic is an iterative generation process which can act as a guide for its subordinate heuristics in order to efficiently find the optimal or near-optimal solutions of the optimization problem [106]. It intelligently combines different concepts derived from artificial intelligence to improve the performance. Meta-heuristics have come to be the most recent development in approximate search methods that have been highly successful for solving complex optimization problems in diverse areas better than their subordinate heuristics. Some of the algorithms that adopt meta-heuristics concepts include Simulated Annealing (SA), GAs, Tabu Search (TS), Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO). Table 5 shows there researchers that adopted various heuristics [29,19], Meta-heuristics [107,108–110,143] approaches in finding the optimal site and size of DG units. The benefits and limitations of each approach are also presented in Table 5. It should be noted, however that there are some theoretical convergences for some of the meta-heuristics under assumptions that cannot be satisfied in real world [106].

Tabu search, employed by Nara at al. [107], Golshan and Arefifar [108] to optimize DG size and locations is a powerful optimization tool that has the ability to avoid entrapment in local minima by using a flexible memory system [150,151]. This approach extensively explores its memory structures to effectively and economically direct the search to attractive regions in the solution space. PSO is swarm intelligence method used in modeling social behavior to guide swarms of particles towards the most promising regions of the search space [152]. Interestingly, PSO adopted by Ardakani et al. [109] is easily implemented and usually results in faster convergence rates than Genetic Algorithms however, its application are limited as it is only efficient in solving unconstrained optimization problems [153].

ACO algorithms use a population of Ants, otherwise known as colony to collectively solve the optimization problem under consideration. Each Ant searches for minimum cost feasible solutions based on its private information and the information available in the local node it visits. As a matter of fact, each Ant of the colony is complex enough to find a feasible solution; nevertheless, a collective interaction among these Ants would yield better quality result [154]. Using ACO algorithm [110] taking DG units constant power sources, considered minimization of DG investment cost and the total operation cost of the system as the objective function in determining the optimal number and location of DG sources in distribution systems. Recently, [143] used PSO with Multi-objective optimization analysis to minimize the real power loss of the system. The proposed algorithm is capable to optimal and fast placement of DG units.

4.3. Artificial intelligence (AI) approaches

In AI, Genetic Algorithms are a particular class of evolutionary algorithm which use techniques inspired by evolutionary

Table 4
Comparison of various analytical approaches/techniques used for optimal planning of DGs.

S. N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
1	**Analytical approaches**				
	Analytical approach based on 2/3 rule	Feeder losses minimization	Simple and helpful in Capacitor placement and DG impact on feeder flow	Do not get exact solution only approximate solution is obtained	Willis [101]
	Analytical approach based on 2/3 rule	Minimize the average power losses The objective function $P_{Loss}(T_i)=\int_0^l\left(\left\|\int_0^x I_d(x,T_i)dx\right\|\right)^2.Rdx$ $V_{drop}(l,T_i)=\int_0^l\int_0^x I_d(x,T_i)dx.Zdx$	Not iterative in nature therefore no Convergence problem	Cannot be directly applied given the size, complexity and the specific characteristics of distribution systems	Wang and Nehrir [102]
	Analytical approach based on exact loss formula	Minimization of power and feeder losses	Simple and Easy to use, Quick results, Not iterative in nature,	May cause erroneous solution for real life system,	Gozel et al. [21]
	Analytical expression and the methodology are based on the exact loss formula	Loss minimization and the objective function based on sensitivity factors of active power	No Convergence problem, quickly calculate the losses	Do not meet robustness requirements	Acharya et al. [99]
	Analytical method with fuzzy logic	Minimizing the loss associated with the active components of branch currents. The objective function is formulated as $P_L=\sum_{i=1}^{b} I_i^2R_i$ $P_{LP}=\sum_{i=1}^{b} I_{ai}^2R_i$ $P_{LQ}=\sum_{i=1}^{b} I_{ri}^2R_i$	Optimal location, which is reducing power loss almost 100% so is reactive power loss and improving voltage regulation	The method was applied only for Single DG unit in practice it is slow	Devi and Subramanyam [103]
	Analytical Method using the exact loss formula	Minimizing the real power losses. Min P_L s.t. $P_G=P_D+P_L$	Fast and accurate in determining the size and location	Not consider the other benefits of DG as well as economics	Mahat et al. [104]
	A loss sensitivity factor, based on the equivalent current injection is formulated	Minimization of losses The objective function is $\text{Ploss}=\sum_{i=1}^{nb}\left\|B_i\right\|^2.R_i=[R]^T\left\|[\text{BIBC}].[I]\right\|^2$	The method is easy to be implemented and faster for given accuracy		Gozel and Hocaoglu [98]
		Minimize power losses and maximize profitability. The objective function is $P_L=\sum_{i-1}^{n} P_{Gi}-\sum_{i-1}^{n} P_{Di}$	Not iterative in nature therefore no Convergence problem	Consider only one DG source (Biomass fueled gas turbine power plants)	Jurado and Cano [105]
	The proposed analytical expressions are based on an improvement to the method that was limited to DG type	Minimizing losses in primary distribution systems. The objective function is based on Exact loss formula $P_L=\sum_{i=1}^{N}\sum_{i=1}^{N}\left[\alpha_{ij}(P_iP_j+Q_iQ_j)+\beta_{ij}(Q_iP_j-P_iQ_j\right]$ $\alpha_{ij}=\frac{r_{ij}}{V_iV_j}\cos(\delta_i-\delta_j),$ $\beta_{ij}=\frac{r_{ij}}{V_iV_j}\sin(\delta_i-\delta_j)$	The proposed method requires less computation, and can lead optimal solution		Duong et al. [140]

Table 5
Comparison of various meta-heuristic approaches/Techniques used for optimal planning of DGs.

S.N.	Type of basic optimization approaches/ techniques	Objective function(s) used	Merits	Demerits	References
1	**Meta-heuristic approaches**				
	Heuristic iterative search approach	Loss minimization using *B* loss coefficient The objective function is $P_L = \sum_{i-1}^{n} P_{Gi} - \sum_{i-1}^{n} P_{Di}$	Iterative and easy to understand	Does not produce accurate results	Griffin et al. [29]
	Heuristic cost–benefit analysis based approach	Minimizing investment and operation costs power loss and the customers energy demand loss minimization The objective function is $J = \sum_{i=1}^{M} (C_{fi}.P_{DGi}^{CAP} + C_{ri}.P_{DGi}) + \rho.P_{ssi} + \sum_{i=1}^{M} C_{Uei}.P_{Uei} + \sum_{i=1}^{M}\sum_{i=1}^{M}\left\{\frac{(\lvert V_i\rvert - \lvert V_j\rvert)^2}{\lvert Z_{ij}\rvert}\right\}.pf.\rho$	Simple to implement relative to analytical and numerical programming approaches	The results are not guaranteed to be optimal	EI Khattam et al. [19]
	Tabu search	Loss minimization $\text{Min } Z = \sum_{t=1}^{t_{max}} \sum_{h=1}^{SC} \text{Loss}_h^t I_{DG\ jk}^t$ $I_{DG\ jk}^t = \sum_{g=1}^{N} B_{jkg}^t . n_t^k$ $(j = 1,2,\ldots,SC, \quad k = 1,2,\ldots,M, \quad t = 1,2,\ldots,t_{max})$	Simplicity, robustness and ease of modification	Some assumption cannot be satisfied or approximated in most practical application	Nera et al. [107]
	Tabu search	Minimizing losses line loading and total required reactive power capacity Function of line loading and reactive power losses	Highly successful in finding near-optimal solutions in many practical optimization problem than their subordinate heuristic	The ability to prove optimality of solutions is lost and approximate solution are obtained	Golshan and Arefifar [108]
	Particle swarm optimization	Minimizing the total power losses Function of total power losses		Computationally inexpensive in terms of memory and speed	Ardakani et al. [109]
	Ant colony optimization	Minimizing the DG investment and total operation cost • Investment cost of DG sources • Operation and maintenance cost of DG sources • Cost of energy buying from transmission grid • Cost of losses Min $Z = \sum_{i=1}^{ncd} C_{DGi} \times K_{IDG\ jk}^t + \sum_{y=1}^{ncd}\sum_{i=1}^{ncd}\sum_{l=1}^{ncd} \text{PW}^y \times C_{i,l} \times K_{EDG} \times T_l + \sum_{y=1}^{nyr}\sum_{j=1}^{nss}\sum_{l=1}^{nld} \text{PW}^y \times C_{SS,l} \times K_{SSl} \times T_l$ $C_{DGi} = \max_{l=1,2,\ldots nld} \{C_{i,l}\}$ $\text{PW} = \frac{1+\text{INfR}}{1+\text{INfR}}$	Improves quality and reliability of the customers' service, quick result	Model does not include the system reliability	Falaghi and Haghifam. [110]
	PSO with multi-objective optimization analysis	Minimize the real power loss of the system. The objective function is formed by combining indices showing the effect of DG presence on real and reactive power losses, voltage profile, MV A capacity of conductors, in addition to short-circuit level of the system	The proposed algorithm is capable of optimal and fast placement of DG units		El-Zonkoly [143]

Table 6
Comparison of various artificial intelligence approaches/techniques used for optimal planning of DGs.

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
1	**Artificial intelligence approaches**				
	A three step procedure, based on Genetic Algorithms and Decision Theory	Minimizing costs of network investment and losses. The objective function to be minimized within the technical constraints The total cost $F_{oG} = \sum_{j=1}^{N_{Tot}-N_{C_p}} F_{0j}$	The procedure furnishes the best DG siting and sizing, taking into account uncertainties introduced by DGs	Fast processing time and accurate result	Carpenelli et al. [113]
			Robustness		Celli and Pilo [114]
	Value-based planning methods	Minimizing losses and the customers interruption costs The objective function max $\frac{\text{Benefit}^{DG}}{\text{Cost}^{DG}}$ $\text{Benefit}^{DG} = K_A\left(\Delta P_{loss}^{avg} + \sum_{i=1}^{N_G} \text{DG}_{gen,i}^{avg}\right) \times \text{CPV}_1 + (\text{CIC}^{DG} - \text{CIC}^0) \times \text{CPV}_2$ $\text{Cost}^{DG} - \sum_{i=1}^{N_G} \text{Cost}_{inv,i} + \sum_{i=1}^{N_G} (\text{Cost}_{oper} + \text{Cost}_{man,i}) \times \text{CPV}_1$	Ability to explore all possible combinations on the solutions set search for many non-inferior solutions in parallel	Premature convergence, Excessive convergence time	Teng et al. [115]
	Genetic algorithm	Minimizing the total real power losses Objective function based on The power loss in line *i*–*j* $S_{Losseij} = S_{ij} + S_{ji}$ $P_{Loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} P_i B_{i0} + B_{oo}$	They work with the discrete and continuous parameters	Lack of accuracy when high-quality solution is required	Mithulananthan [57]
	Combination of genetic algorithm techniques	Minimization the network losses and maximize a benefit/cost relation The function is defined as $F = \frac{\text{Benefit}(B)}{\text{Cost}(C)}$ Losses cost = cost/kW × losses (kW)	Use transition probabilistic rules and not deterministic rule	Computationally inexpensive in terms of memory and speed, robust, with moderate computer requirements	Borges and Falcao [28]
		System energy loss minimization Min $P_{loss}\{DG(i, size)\}$ $P_{Loss} = \sum_{line(i,j)=1}^{m} P_{line(i,j)}$ $P_{line(i,j)} = P_i - P_j$	Less susceptible to local minima and noise	Placing a DG, where peak load condition is evaluated may not provide the best location for minimum loss	Singh et al. [116]
	Load flow algorithm is combined appropriately with GA	Voltage profile improvement and loss reduction in distribution network The objective function $axF = k_1\left\{\text{Max}\left[0, \frac{1}{n}\sum_{i=1}^{n}(\text{Volatge\%}_{i_{with\ DG}} - \text{Volatge\%}_{i_{withoutDG}})\right]\right\} + k_2\left\{\text{Max}\left[0, \sum_{j=1}^{m}(P_{j_{without\ DG}} - P_{j_{with\ DG}})\right]\right\} + k_3\left\{\text{Max}\left[0, \sum_{j=1}^{m}(Q_{j_{without\ DG}} - Q_{j_{with\ DG}})\right]\right\}$	They are Gradient based		Saedighizadeh and Rezazadaeh [117]

Table 6 (*continued*)

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
		Minimization of system losses, network disruption and cost and maximizing DG rating The objective function $C = \sum_{i=0}^{y} \frac{C_i}{(1+r)^i}$ £ $E = \sum_{i=0}^{y} \frac{E_i}{(1+r)^i}$ kWh Min $F(X) = \frac{C}{E}$ £/kWh	Simple and less time		Kuri et al. [118]
	A GA technique based on the hypothesis of natural selection	Minimize power losses of grid lines Min $P_{Loss} = \mathrm{Re}\left(\sum_i V_{line,i}, I_{linej}\right)$	Simple and quick for small system	To enlarge the number of feasible production sizes the discretization step can decrease. Eventually a more complex algorithm	Haesen et al. [119]

mechanism such as selection, crossover and mutations [111,112]. They are efficient optimization search techniques employed in finding the exact or near-optimal solutions in multi-objective optimization problems.

Applications of AI to complex problems are found in several disciplines such as bioinformatics, computational science, engineering, chemistry, mathematics etc. A genetic search is usually preceded with a randomly generated initial population, covering the entire range of possible solutions, otherwise known as the space. The fitness of each individual in the population in each generation is then evaluated and thereafter modified to form a new population of better solutions. This new populations is then used in the next iteration of the algorithm that terminates either when a satisfactory level of fitness has been attained or when a maximum number of generation have been produced in the population.

Of the literature reviewed in this study, some researches [28,57,113,115,116,117,118,119] adopted the GAs based AI approach in finding the optimal size and site of DG units power distribution systems, though Carpinelli et al. [113] did not optimize size in their work. For the general benefits and the downsides of this approach is shown in Table 6.

4.4. The genetic algorithms hybrid approaches

The major drawbacks of the genetic algorithms have led many researchers to considering the combination of GA and one other optimization search techniques together for a better solution. GA is known to be very good at finding good global solutions but not so efficient in determining the absolute optimum [120]. Other techniques that are quite efficient in finding the absolute optimum in a limited region when combined with GA would certainly improve the efficiency of GA while at the same time overcome the lack of robustness in the other search techniques. Gandomkar et al. [127,128] incorporated Tabu search in the production phase of GA to avoid the major drawbacks of the classical Simple Genetic Algorithm (SGA). In the same vein, Hereford Ranch algorithm [31,127,128] adopts sexual differentiation and selective breeding in choosing parents for genetic string as a way of improving the SGA for a better solution. Further, a new hybrid algorithm of genetic and simulated annealing was proposed [20,128] for evaluation of DG size and site in distribution networks. The results of the hybrid demonstrated its effectiveness over that of SGA in terms of quality and number of iterations. The constraint techniques was combined with GA [122,121]) to create a set of non-inferior solutions with an iterative procedure. Choosing the best optimal solution in the set of feasible solutions was then used for existing distribution networks.

Mardaneh and Gharehpetian [126] and Gandomkar et al. [127] in their own case combined OPF with GA with the aim of finding the best combination of sites within a distribution network for connecting a specified number of DGs. The Optimal Power Flow (OPF) computes the fitness function of GA that is fed back to the GA to search for the optimal connectable capacity of DG.

The main idea of solving of fuzzy non-linear goal programming [125] is to transform the original objective functions and constraints into the equivalent multi-objective functions with fuzzy sets evaluate their imprecise nature.

The problem is solved with GA without the need to transform the non-linear problem into a linear model. This approach is good for solving constrained multi-objective problems. Haghifam et al. [124] proposed a specialized NGA-II as solution algorithm to determine the Pareto-optimal multi-objective solution for DG placement in distribution systems.

A combined genetic algorithm and optimal power flow with Multistage Distribution Expansion Panning (MSDEP) recently proposed a fast and efficient approach [147] which is used to

Table 7
Comparison of various genetic algorithms hybrid approaches/techniques used for optimal planning of DGs.

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
1	**Genetic algorithms hybrid approaches**				
	Combination of GA and ε-constrained multi-objective (MO) programming	Minimization of the cost of network upgrading, power losses cost, the cost of energy not supplied and customer energy purchased cost A mathematical expression of the problem is Min $C\ (X(U))=\min[C_U,\ C_L,\ C_{ENS}, C_E]$			Celli et al. [121]
	A methodology is presented based on multiobjective programming and decision theory (a double trade-off procedure)	Minimizing costs losses A mathematical expression of the problem is Min $C\ (X(U))-\min[F_1,F_2,F_3]$	Able to take into account quickly and precisely in a real-size distribution network scenario many different planning alternatives		Carpenelli et al. [122]
	Combined GA–OPF	Minimizing the capacity of DG. The objective function $f_{OPF}=\sum_{g=1}^{n} C_g.P_g$	The hybrid method are better than SGA in terms of solution quality and number of iteration	Computationally demanded	Siano et al. [123]
	Non-dominant sorting, genetic algorithm (NSGA-II)	Minimization of the monetary cost index, technical risks and economic risks Monetary objective function of DG placement can be formulated as $\text{Min}\ \tilde{f}_M=\sum_{i1}^{NN} C_{DGi}IC_{DG}+8760\sum_{t1}^{T}\mu^t\sum_{i1}^{NN}P_{DGi}\text{OC}_{DG} -8760\sum_{t1}^{T}\mu^t\sum_{i1}^{NN}(\tilde{P}_{Loss0}-\tilde{P}_{Loss0})C_T$ $P_{Loss}=\sum_{(i,f)\in\alpha_N}\Delta\tilde{V}_{ij}^2\frac{R_{ij}}{Z_{ij}^2}$ $\mu=\frac{1}{1+d}$	A powerful decision-making tool for risk management in distribution networks with DG installation and operation	Combined GA-OPF Can find a much wider spread of solutions	Haghifam et al. [124]
	Combination of Fuzzy non-linear goal programming and GA-OPF method	Minimization power loss cost The objective function Min objective func. $=K_e\sum_{i=0}^{nt}T^iP_{loss}^i$	Obtain the most compromised or satisfied solution among multi-objectives		Kim et al. [125]
	Combination of GA and OPF method	Minimization of active and reactive power generation and installation cost The objective function $C=\sum(C_P+C_Q)+\sum C_I$	They are gradient based		Mardaneh and Gharehpetian [126]
	Conventional GA and Hereford Ranch algorithm (HRA) Improved genetic operators such as HA (heuristic and arithmetical crossover) and TM (two-point mutation) with non-uniform mutation are proposed	Minimization of total active power losses The objective function in given in terms of Loss minimization index, penalty factor, maximization of fitness function	Obtaining the fast convergence and preventing HRA from premature convergence		Kim et al. [31]
	A new algorithm based on integrating the use of genetic algorithms and simulated annealing methods	Minimizing distribution power losses The objective function in this optimization problem is: $f=\sum_{i-1}^{n}P_i$ penalty function $f=\sum_{i-1}^{n}P_i+\alpha\left(\sum_{k-1}^{L}P_k-C\right)$	Better characteristics of the GA–SA algorithm in comparison with the SGA specially in terms of; solution quality and number of iterations		Gadomkar et al. [127]
	Combined GA and Tabu search	Minimizing the power frequency of the harmonics losses The objective function in this optimization problem is: $f=\sum_{i-1}^{n}P_i$ Penalty function $f=\sum_{i-1}^{n}P_i+\alpha(P_j+\cdots+P_k-C^*)$	Good solution quality and less number of iteration		Gadomkar et al. [20]
	Combined GA and simulated annealing	Minimizing distribution power losses The objective function in this optimization problem is:	Much better terms of solution accuracy and		Gadomkar et al. [128]

Table 7 (*continued*)

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
		$f=\sum_{i-1}^{n} P_i$ $\text{Minimize}\, f=\sum_{j=1}^{F}\left(\sum_{i=1}^{B_j} P_{ij}+\alpha\left(\sum_{k=1}^{L_j} P_{kj}-C_j\right)+P_{hj}\right)$	convergence process		
	A multiobjective genetic algorithm is employed	This paper investigates the effect of load models in size and location planning of a DG	GA runs multiple numbers of times at some cases the suboptimal solutions are also obtained	Combined GA and multiobjective optimization	Singh et al. [142]
		The objective function is based on the load models and several indices	It becomes prohibitive for large system		
	A combined genetic algorithm and OPF multistage distribution expansion planning	Minimization of overall cost in which reliability is included as Customer Outage Cost (COC) Mathematical formulation of the objective function is given Min $v=\text{ic}+\text{oc}+\text{rc}$ $\text{ic}=C_{RF}\left(\sum_{i\in S}\text{IC}_i^{SS}+\sum_{j\in F}\text{IC}_j^{FD}+\sum_{k\in G}\text{IC}^{DG}(S_{k-cap}^{DG}+S_{RS}^{DG})\right)$ $\text{oc}=\sum_{t\in T}T_t\left(\sum_{i\in S}\text{OC}_k^{DG}\times P_{k-t}^{DG}+\sum_{i\in S}\text{EC}_{i-t}^{SS})\right)$ $\text{rc}=\sum_{t\in T}\frac{T_t}{8760}\sum_{d\in D}\sum_{e\in E}P_{d-t}^{LD}\times f_d(r_{d,e})\times\lambda_{d,e}$	Fast and efficient		Falaghi et al. [147]

minimization of overall cost in which reliability is included as Customer Outage Cost (COC).

Planners can select the most satisfactory solution based on their professional experience. This feature illustrates the possibilities experience of the approach for practical application and the flexibility of the method. Table 7 shows these approaches with their relative benefits and demerits.

4.5. Other approaches

The first approaches aims at finding the optimal sites for DG units of specified discrete capacities. The prejudging of DG capacity, however, may mean that some smaller or larger opportunities than the chosen standard would not be selected which could result in non-optimal solution. On the other hand a second approach that requires the user to predefine the locations of interest in the network, leaving the algorithm to determine the optimal capacity of DG may lead to the optimal solution that contains a number of small-size capacities of DG that might not be economically viable to implement in actual sense. However, leaving the algorithm to optimize both size and locations of DG sources is adjudged by the authors of these studies to yield the best optimal solution to real life scenarios.

Apart from the approaches discussed in the previous sections, other techniques used in finding the optimal size and locations of DG units in power distribution systems considered here include the Largrangian Multipliers (LM) [129,130] binary decision variables [131], voltage stability constrained OPF [133,132], CPF-based iterative algorithm [134], sensitivity analysis [136,135], linear programming [137,138], locational marginal price [9], and second order algorithm [139], probabilistic approach using a mixed integer nonlinear programming (MINLP) [79,141], conventional iterative search technique [144], nodal pricing [145], multi-objective problem a novel approach based on dynamic programming [146], a value based approach [148], a static fuzzy multiobjective approach and [149]. Details of the objective function(s), the benefits as well as the limitations of each these methods are shown in Table 8.

5. Conclusion

In this paper, the effort is made towards the overview of the relevant aspects related to DG and its impact that DG might have on the operation of distributed networks. This report evolve the basics of DG, DG definition, current status of DG technologies, potential advantages and disadvantages; optimal placement of DG systems and uncertainties, optimizations techniques/methodologies used in optimal placement and impacts of DG in distribution systems. This paper also reviewed the benefits of DG on loss minimization, voltage profile improvement and reliability for a simple distribution system. Therefore, these factors have to be considered very carefully in order to determine the optimal planning of DG in distribution system.

On the whole, the various methodologies involved in DG placement by researchers revealed that when finding a global optimal solution of complex multi-objective optimization problems, particularly those with many local optima.

One is generally faced with a fundamental conflict between accuracy, reliability and computational time. It is often impossible to arrive at solution that optimizes all objectives without a trade-off. Consequent upon that fact, it is concluded that hybrid of two or more optimization techniques would yield a more efficient and reliable optimal solution. By so doing, the techniques would have combined their strength and mitigate each other's limitations in arriving at the best possible solutions. The uncertainties involved in system planning and operation become larger and certainly new methods need to be developed to analyze and to foresee the behavior of the systems.

Table 8
Comparison of various other approaches/techniques used for optimal planning of DGs.

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
1	**Other approaches**				
	Lagrangian multipliers (LM)	Minimizing operating costs Objective function Min $G(x)$ s.t. $F(x)=0$; $\underline{H} \le H(x) \le \overline{H}$ $\underline{x} \le x \le \overline{x}$ where $G(x) : \Re^n \rightarrow \Re$	Easy to solve, can handle more constraints more easily	Becomes less computationally less efficient as the order of elements increase	Rosehart and Nowicki [129]
	An OPF based wholesale electricity market	Social welfare and profit maximization The objective function is formulated $\max \sum_{i=1}^{N} (B_i(P_{Di}) - C_i(P_{Gi})) - C(P_{DGi})$	Yields results that are significantly superior to linear programming	Gives a necessary but not sufficient optimally in constrained problems	Gautam and Mithulananthan [130]
	Binary decision variables	Minimizing DG's investment and operating costs. The objective function considered are investment and operating costs of DG	Provides accurate optimal decision without any need to round the solution	Limited by the high dimensionality of power systems	EI-Kahttam et al. [131]
	Voltage stability constrained OPF	Minimizing the real power loss	Can solve large and complex power systems	Cannot handle problems real with discontinuities and non-convexities	Momoh and Boswell [132]
		The general formulation objective function can be summarized minimizing a welfare cost function subject to power balance, network security and power market constraints Minimize $C_S^T P_S - C_C^T P_D$	It takes relatively short time to achieve this	Multiple minima that can differ substantially may exist	
	Optimal power flow	Maximizing DG capacity The objective function (f) and associated formula is given as follows: $\min f(\psi) = \sum_{I=1}^{N} -c_I \times \mathrm{MW}_i^0 (1-\psi_i)$	Capable optimizing highly complex problems that include many variables, overcomes some of the earlier limitation in items of flexibilities, reliability and performance requirements	Limited by the high dimensionality of power systems Solution may not be optimal when the function is highly complex Optimize only one specific objective Can handle search global optimal. Easily trapped in local optimal	Harrison and Wallace [133]
	CPF-based iterative algorithm	Minimizing active and reactive power losses, maximizing power transfer capability and voltage stability margin generation and installation cost The objective functions is $Q_{Loss} = \frac{(P_{Load}-P_{DG})^2 + (Q_{Load}-Q_{DG})^2}{V^2} X_{Line}$	Robust and effective	Limited by the high dimensionality of power systems	Hedayati et al. [134]
	Sensitivity analysis	Minimization of power losses The objective function is $P_{Loss} = \sum_{i=1}^{nbr} \lvert I_i \rvert^2 r_i$ $Q_{Loss} = \sum_{i=1}^{nbr} \lvert I_i \rvert^2 x_i$	Capable to directly calculate the change in all network variables	Does not yield valuable result at critical point of transfer limit due to singularity of power flow Jacobean	Kashem et al. [135]

Table 8 (*continued*)

S.N.	Type of basic optimization approaches/techniques	Objective function(s) used	Merits	Demerits	References
	Sensitivity analysis of the power flow equations	Maximizing DG capacity The objective function is based on two voltage sensitivity index (VSI) and loss sensitivity index (LSI)	Can directly account for the impact of simultaneous change to several network parameters	Uncertainties are not considered	Popovic et al. [136]
	Linear programming	Maximizing DG capacity The proposed objective function is $J=\sum_{i=1}^{N} P_{EGi}$	It is easy to implement Good for solving problems with linear objective functions and constraints High computational efficiency	Objective function an capacity the constraint must be linear Reducing the world models of into a set of linear equations is usually very difficult	Keane and O'Malley [137]
	Combined GA and simulated annealing	Maximizing the amount of generation exported to the transmission system The objective function is $P_{Tx}=\sum_{j=1}^{N}[P_{DGi}(1-\eta_{ij})-P_{LDi}(1-\rho_{ij})]$	Approach is effective for variable and intermittent forms of generation (no. of DGs)		Keane and O'Malley [138]
	locational marginal price (LMP)	Minimization of generation cost The objective function formulated as $\min_{P_g} \sum f_i(P_{gi})$	Very fast and efficient	The size and complexities of distribution systems	Agalgonkar et al. [9]
	Gradient and 2nd order algorithm	Minimization of power losses, var losses and line loading of the system The objective function in this optimization problem is: Minimize $f=\sum_{i-1}^{n} P_i$	The 2nd order algorithm is more efficient than the earlier algorithm A given accuracy in the result can be achieved Converges faster than the existing first order methods	Some important operation constraints. e.g. voltage limits are not considered Gives a local optimal point Not efficient due to a large number of load flows computational	Rau and Wan [139]
	Probabilistic approach using a mixed integer non-linear programming	Minimize the annual energy losses of wind-based DG units The objective function formulated as minimise cost$=\sum_{g-1}^{N} P_{loss\ g}\times P(C_g)\times 8760$	The proposed technique can closely mimic the actual loss calculations resulting in more accurate also Considered the uncertainty		Atwa et al. [79]
	The methodology is based on generating a probabilistic generation-load model and MINLP	Minimize the annual energy losses The objective function minimise cost$=\sum_{g-1}^{N} P_{loss\ \ g}\times P(C_g)\times 90$	The proposed technique guarantees the optimal fuel mix for loss minimization during the entire planning period and ensures that, for all possible operating conditions, no system constraints will be violated		Atwa et al. [141]
	Conventional iterative search technique along with Newton Raphson method	The objective is to lower down both cost and loss The objective function OF$=C(P_{DG})+W\times E$	Better than the simulation results obtained		Ghosh et al. [144]
	New methodology based on nodal pricing	Loss reduction, profit maximization and voltage improvement The objective function maximize $(P^{no_{DG}}_{elect}-P^{DG}_{elect})$	It is easy to implement		Singh and Goswami [145]
	Multi-objective problem a novel approach based on dynamic programming	Minimize power loss of the system and enhance reliability improvement and voltage profile The objective function Max Z=benefits costs$=$BPV$(B1)+$BPV$(B2)-[C1+$CPV$(C2)+$CPV$(C3)]$	Efficient and easy, reliability consider except other constraints	DG consider as a constant power source	Khalesi et al. [146]
	A value based approach The system was modeled as a Markov process and state based modeling techniques were used	The analysis focused almost exclusively on the reliability performance but considered reactive power support requirements and distribution losses as well	Easy to implement		Banerjee and Islam [148]
	A static fuzzy multiobjective approach	Environmental–technical–economic based on profit margin The objective functions are optimized	The proposed model was simple and more suitable for energy market environments		Zangeneh et al. [149]

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